Undergraduate Student Satisfaction and Achievement at the GetWET Observatory: A Fluid Learning Experience at Colorado State University

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ABSTRACT

The GetWET Observatory was developed as part of an overall course redesign of the Introductory Geology Laboratory at Colorado State University to improve student learning of key surface and groundwater concepts for nonmajors in science, technology, engineering, and mathematics. Consisting of six groundwater monitoring wells, the GetWET Observatory is adjacent to a gauged perennial creek on campus property. Students complete hands-on, field-based exercises related to surface and groundwater, with emphasis on local water quantity and quality. Overarching questions about the responsiveness of the curricular changes to student's needs were evaluated through a student perception survey. The effectiveness of student learning of key concepts of surface and groundwater was evaluated through pre- and post-knowledge assessments. Results of the perception survey indicate that the needs of students from all majors and colleges were equally met, that males report a higher rate of enjoyment of the GetWET experience than females, that weather plays an important role in student enjoyment, that modifications to the groundwater exercise focused the learning on larger concepts of surface and groundwater, and that student perceptions of the quality of the lesson increased with the curricular revision. Student responses indicate we have created an affirmative laboratory environment at the GetWET that supports positive student attitudes conducive to maximum learning. Students whose teaching assistant was a graduate student had much higher perceptions of the quality of the lab, higher satisfaction with the lab, higher perception of the quality of the lesson, and a better understanding of the relationship between themselves and ground and surface water. There was no significant difference in student knowledge baseline on pre-tests over three semesters of data collection. Mean gains in student scores between pre- and post-tests ranged from 0.63 to 0.76, with a 1.60 mean gain for a small number of laboratory sections taught by graduate teaching assistants who had more hydrogeological background. A decrease in student gain scores followed curricular revision along with a simultaneous significant increase in student's perception of the quality of the lesson. Additional data will be collected to determine if the decrease in gain scores is attributed to teaching assistant composition or a less effective laboratory exercise. Pre- and post-knowledge tests are also useful instruments for tracking basic groundwater knowledge of teaching assistants and their teaching effectiveness. Additional and ongoing training of all GEOL121 teaching assistants has strengthened the overall learning experience for undergraduates at the GetWET Observatory.
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INTRODUCTION

In the semi-arid western United States, groundwater is an ever increasingly vital natural resource, and the protection and conservation of this resource through wise use and informed voter choices relies on accurate public knowledge of groundwater. With every election, the citizens of Colorado and throughout the west are faced with issues related to water projects ranging from new or enlarged dams, water rate fee increases, taxes on new development to finance water treatment and distribution, and municipal groundwater well installations. As voters, students need working knowledge of the pressing water issues facing the western United States, such as rapid development, drought, and increasing climate variability. As a land-grant institution, Colorado State University has a unique goal of educating the public beyond our formal classrooms. In our classrooms, we usually have a one-semester opportunity in large lecture courses to enhance student comprehension of basic surface and groundwater concepts to promote water literacy among nonscience majors. This mission is especially significant given the particularly troublesome nature of teaching groundwater concepts filled with confusing vernacular (Meyer, 1987; Dickerson and Dawkins, 2004), the complex three-dimensional nature of groundwater (Dickerson *et al.*, 2005), poor and erroneous illustrations in introductory textbooks (Wampler, 2000), the often incomplete approach of teaching groundwater in the context of a simplified water cycle, and the poor coverage and lack of understanding of groundwater processes presented in the media.

In an effort to fill a critical gap in student opportunities to learn about surface and groundwater concepts in a large enrollment Introductory Geology Laboratory course for nonmajors (GEOL121), funding was secured through a grant from the National Science Foundation (NSF) to develop the **G**round**W**ater **E**ducation and **T**eaching (**G**et**WET**) Observatory. The impetus behind the GetWET Observatory was a wholesale course redesign of the GEOL121 Laboratory (Fig. 1) initiated to foster improved experiential, inquiry-based learning through hands-on, field opportunities that capitalize on the geologically rich location along the Colorado Front Range. We report, herein, on the development of the GetWET Observatory, and student use and achievement through a multipart exercise on surface and groundwater (Fig. 1).

Pedagogical Basis

Development of the GetWET Observatory is based on educational best practices recommended through science, technology, engineering, and mathematics (STEM) education

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FIGURE 1: Flow chart of steps involved in incorporating the GetWET Observatory into the general education Introductory Geology Laboratory at Colorado State University as part of a larger course redesign. Results from development of the *Groundwater Exercise* through the steps to *Additional Teaching Assistant Preparation* are reported herein.

reform, which promote student participation through inquiry and the "excitement of discovery," and allow students to learn science by participating in the scientific process (National Science Foundation, 1996). Abundant research on improved student learning through hands-on, field based experiences (e.g., Kolb, 1984; Saunders, 1992; National Research Council, 1997; Rimal and Stieglitz, 2000; Siebert and McIntosh, 2001; American Association for the Advancement of Sciences, 2004; Elkins and Elkins, 2007) provided convincing impetus for changes to the GEOL121 curriculum, as did the desire to increase student enthusiasm for learning science by allowing them to do science (e.g., Kirchner, 1994; Rahn and Davis, 1996; Plymate *et al.*, 2005). Of greatest pedagogical importance to us is to (1) create a classroom environment that is most conducive to student learning and responsive to student needs (Fraser, 1994), (2) provide more relevance for our students through locally based, timely issues related to groundwater, (3) give students a sense of ownership through self-collected data (Dunnivant *et al.*, 1999), (4) link to a day-long, capstone fieldtrip to the headwaters of the GetWET watershed near Horsetooth Reservoir (Fig. 2; Warnock *et al.*, 2004), and (5) increase learning through hands-on, small-group experiences (Bykerk-Kauffman, 1995; Springer *et al.*, 1998). Ultimately, our goal is to provide students an exciting opportunity to observe, measure, analyze, and interpret the connections between groundwater and an adjacent perennial stream within the local watershed on campus property, and give students a chance to appraise, first hand, the impacts of humans on groundwater resources.

While our approach of developing a groundwater well field on campus for student use is not unique (Fletcher, 1994:, Hudak, 1999; Laton, 2006; Day-Lewis, 2006) what is most useful to us, and likely useful to the broader geoscience education community, is the assessment methods and our approach of incorporating assessment outcomes into tangible laboratory modifications. Two governing questions

> *To what extent has the curriculum revision of the GEOL121 Introductory Geology Laboratory been responsive to the knowledge and skill needs of nonmajor students?*

and

> *What is the effectiveness of the developed experiences for nonmajors within the GEOL121 Introductory Geology Laboratory course?*

provide the basis for this paper. The main objective is to report on student perceptions of their experience and student learning about surface and groundwater interactions at the GetWET Observatory. The GetWET was also fully integrated into the curriculum for geology majors, whereby four upper division classes in geosciences utilize the facility at different times while students progress through the major. Results of curricular changes for upper division courses are beyond the scope of this paper, as are dissemination and outreach results of the project. Refer to the GetWET project website for details about dissemination and outreach (http://getwet.colostate.edu/).

BACKGROUND

Colorado State University (CSU) is a large land-grant institution with approximately 25,000 resident-instruction students of which approximately 80% are Colorado residents. Of the students that are U.S. citizens, 13% are ethnic minorities. Average incoming freshmen are in the 72nd percentile of high school graduates, have a high school grade point average of 3.5, and a composite ACT score of 24. The student to faculty ratio at CSU is 17:1.

The GEOL121 Introductory Geology Laboratory is a one-credit, stand alone course that satisfies the general education science laboratory requirement. Seventeen sections of the laboratory are taught every week, requiring four graduate teaching assistants and as many as four undergraduate teaching assistants. Usually the undergraduate teaching assistants are senior geology majors who have high grade point averages, are recommended by the geoscience faculty, and may or may not express an interest in teaching. The undergraduates are paid a nominal fee, and receive one credit of Supervised College Teaching which appears on their transcripts.

Students enrolled in the GEOL121 Laboratory also enroll, as a pre- or co-requisite, in one, three-credit lecture course, either Physical Geology (GEOL120), Environmental Geology (GEOL122), or Geology of Natural Resources (GEOL124). Two of the three lecture courses are taught each semester and have traditionally large enrollment with as many as 250 students. The lecture courses generally follow the laboratory syllabus so students hear topics first in lecture then get the laboratory experience. There is a separate Introductory Geology course offering for students in STEM majors. This course, GEOL150, has a typical enrollment of 40 students and is a combined four-credit lecture and laboratory course.

On-campus Well Field and Instructional Materials

The GetWET Observatory consists of six groundwater monitoring wells adjacent to Spring Creek, a tributary of

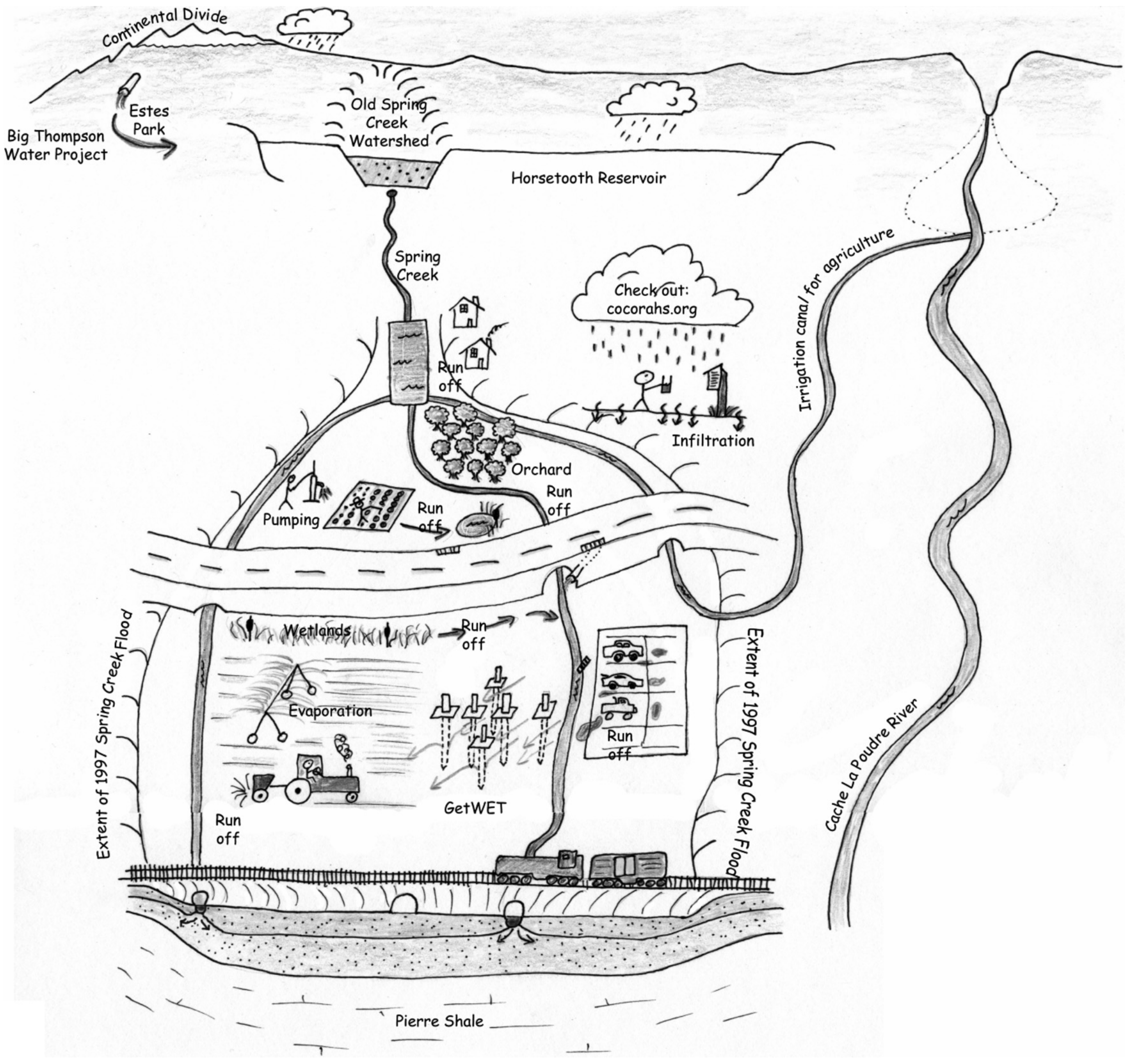

FIGURE 2: Cartoon of geographical location and contextual setting for the GetWET Observatory. Perspective is to the west, with the CSU campus located to the right between the irrigation ditch and the Cache La Poudre River (by A. Warnock from http://getwet.colostate.edu/concepts.html).

the Cache La Poudre River, the main river that flows east through Fort Collins (Fig. 2) before joining the South Platte River near Greeley, CO. Spring Creek is a perennial stream in an otherwise ephemeral setting due to storm water discharge from nearby campus roads and parking lots. As such, Spring Creek is a losing stream during all times of the year, with surface water levels elevated in the spring during snowmelt runoff, and at an annual low during the fall base flow conditions. The groundwater wells tap the shallow aquifer of Quaternary alluvial fill overlying Cretaceous-age Pierre Shale bedrock. Well depths average 5.85 m and wells are approximately 5.0 m apart, with the north-most well 5.90 m from the right bank of Spring Creek. The GetWET Observatory complements the agricultural area that forms the floodplain of Spring Creek (Fig. 2) and exists within a dynamic urban watershed illustrating fluxes of water on different time scales that form a challenging and interesting basis for student learning (Rathburn, *et al.,* 2006).

The groundwater exercise at the GetWET is one piece of a multipart laboratory focused on fluvial systems, flood hazards, and surface water and groundwater hydrology. Students reconstruct the July 1997 Spring Creek Flood in Fort Collins (Richardson, 1998) the week following the GetWET laboratory to collect data on channel geometry, measure discharge, evaluate high water marks, interpret precipitation maps of the convective thunder storm that generated the flood, and discuss urbanization influences that exacerbated the flood hazard. Because of the abundance of impervious surfaces in the basin, the Spring Creek hydrograph can be very flashy, with water levels rising rapidly during rain events. A surface water monitoring station has been installed along Spring Creek within the GetWET Observatory to allow students a means of comparing surface flow to groundwater flow.

METHODS

Formative assessments of the GEOL121 laboratory exercise at the GetWET Observatory were conducted and the data were used to guide refinement of the course, the laboratory manual, scheduling of laboratory exercises, and teaching assistant training. Two approaches were implemented to evaluate the overall effectiveness of the GetWET Observatory at enhancing undergraduate learning. First, student questionnaires, or perception surveys (Fig. 1), were distributed to evaluate the quality of the laboratory exercise at the GetWET. Second, student achievement was evaluated via pre-and post-knowledge assessments of basic surface and

TABLE I: Knowledge assessment given prior to and following instruction on surface and groundwater concepts in GEOL121 Introductory Geology Laboratory. Mean pre-and post-test scores and mean gain score for Fall 2007, Spring 2008, and Spring 2009 shown in bottom row. (Questions developed in collaboration with A. Warnock.)

Concept Questions	Multiple Choice Answers	Bloom	level[1]	
1. If one room is filled with boulders and another room is filled with sand, the porosity	a) is greater in the room with boulders b) is greater in the room with sand c) is the same in both rooms d) cannot tell difference in porosity from the information given	2	Comprehension	
2. Why do streams flow when it is not raining?	a) because the groundwater table is above the bottom of the stream channel b) because it is raining somewhere else c) because glaciers are melting forming rivers in the mountains d) because people pour filtered waste water back into the stream	3	Application	
3. Would a leaking septic tank near a losing stream pollute the stream?	a) yes, because the stream would draw up the pollution to the stream b) yes, because pollution is less dense than water c) no, because the pollution is more dense than water d) probably not, because groundwater flows away from the stream	4	Analysis	
4. The direction of groundwater flows is influence primarily by	a) the velocity of the nearby stream b) the gradient of the water table c) the porosity and permeability of the substrate d) the amount of future precipitation	24	Comprehension Analysis	
5. What would cause the electrical conductivity of surface water and groundwater to increase?	a) algal bloom b) fish consuming dissolved oxygen c) goose feces in the water d) road salt washing into the water	3	Application	
	Semester	F 2007l[2] (n=78)	S 2008l[3] (n=204/175)	S 2009[2] (n=112)
	Pre -test mean (SD)	2.18 (0.89)	2.33 (1.14) / 2.34 (1.21)	2.08 (0.97)
	Post-test mean (SD)	3.78 (0.88)	2.96 (1.08) / 3.10 (1.04)	2.75 (1.13)
	Gain score mean (SD)	1.60 (1.07)	0.63 (1.25) / 0.76 (1.24)	0.67 (1.21)

[1]From Bloom's taxonomy of educational objectives (Bloom *et al.*, 1956).
[2]Only graduate teaching assistants administered pre- and post-tests, original exercise Fall 2007.
[3]Graduate and undergraduate assistants administered pre- and post- tests, revised exercise; 2.34, 3.10, and 0.76 are average pre- and post-scores and gain score after removing one assistant's data.

groundwater concepts. In addition, comments from standard university-wide, end-of-semester evaluations and teaching assistant feedback were also used to evaluate student knowledge gains and satisfaction.

Student Perception Survey

Formative assessment in the form of a pilot questionnaire comprised of demographic information and 36 Likert-type questions was developed and administered during academic year 2007–2008. The overarching question addressed in the perception survey is "*To what extent has the curricular revision to the GEOL121 course been responsive to the knowledge and skill needs of nonmajor students?*" A series of subquestions were created to evaluate this question to form composite indices measuring: (1) *Student perceptions of the quality of the laboratory exercise*, (2) *Student satisfaction with the laboratory exercise*, (3) *Quality of the lesson*, and (4) *Student perceptions of the relationship between groundwater and surface water*. Respondents rated a series of statements related to each of these dimensions using a five-point scale (i.e., strongly disagree, mildly disagree, neither disagree nor agree, mildly agree, or strongly agree). All items were positively worded, and a factor analysis conducted with the items used to create the scales shows strong loadings on each of the four indices, suggesting strong content validity of the instrument. The questionnaire is available from the authors upon request.

Pre- and Post-Knowledge Assessment

To address the question "*What is the effectiveness of the developed experiences for nonmajors within the GEOL121 Introductory Geology Laboratory course?*" A pre-test/post-test approach was taken to evaluate student knowledge of fundamental surface and groundwater concepts, utilizing the ideas of Bloom *et al.* (1956) on high-order thinking. Prior to any presentation of water concepts in lecture or laboratory, students in GEOL121 were given a five question multiple choice test to evaluate what they know about surface and groundwater (Table I). The five questions are directed at

TABLE II: Summary of revised groundwater exercise completed at the GetWET Observatory by students in GEOL121 Introductory Geology Laboratory at CSU.

Groundwater Exercise	Key Concepts	Learning Activities
Part 1. Well drilling and core descriptions	Well drilling techniques, well logs, water table, basic alluvial stratigraphy, grain size, local bedrock properties	Watch video on well drilling and installation, observe preserved core, evaluate porosity and permeability of strata and relationship to water table
Part 2. Create a map of the water table	Water table, porosity, permeability, hydraulic head, hydraulic gradient, surface water elevation, alluvial aquifer and local groundwater flow, surface water flow, regional aquifer, contouring, hydrogeologic cross sections illustrate gaining versus losing conditions, field measurement techniques	Measure depth to groundwater and surface water level, plot elevations on map, contour water table, develop flow net, calculate hydraulic gradient, interpret groundwater flow, compare to regional groundwater flow, compare to surface water flow, construct hydrogeologic cross section, interpret gaining or losing nature of Spring Creek
Part 3. Evaluate water quality of groundwater and surface water	*p*H, temperature, specific conductance, total dissolved solids, dissolved oxygen, field sampling techniques and instruments, surface versus groundwater quality, federal drinking water regulations, contaminant transport	Measure *p*H, temperature, EC, TDS, and DO of wells and Spring Creek, evaluate differences between groundwater and surface water quality, predict how human activities might affect each of the parameters, calculate contaminate transport rate

specific surface and groundwater topics relevant to the GetWET Observatory and Spring Creek, with the distracters, or incorrect responses, drawn from answers to open-ended questions given to students in the GEOL120 lecture course the previous semester. Three weeks later, after all water-related topics were covered in lecture and laboratory, the post- test consisting of the same five questions was administered a second time. The pre- and post-test was administered over three semesters.

Groundwater Instructional Materials

An exercise on groundwater, with an emphasis on surface water/groundwater interactions was written for students to complete at the GetWET Observatory. The main objectives of the exercise were to promote student learning of basic groundwater concepts including local alluvial and regional aquifer properties, groundwater discharge, surface-groundwater interactions, and water quality. An initial groundwater exercise using the GetWET was developed in Fall 2006 and used again in Spring 2007 and Fall 2007. Before the initial groundwater exercise was presented to students, it was critiqued by teaching assistants for the course as well as a hydrogeology colleague. The initial exercise required students to complete multiple calculations, including Darcy flux and specific discharge, based on field measurement from wells at the GetWET. In Spring 2008, a revised groundwater exercise was introduced into lab because the original version was deemed too difficult and quantitative for the students based on data from student perception surveys (one semester), feedback in class (three semesters), and end-of-semester evaluations (one semester). In addition, according to teaching assistant input (three semesters), the exercise concentrated more on calculations than on concepts, and left many students confused about groundwater and the interactions between water quantity and quality in Spring Creek and within the adjacent alluvial aquifer. Examples of student feedback on the original exercise, which are representative of the class as a whole included:

> I have basically no science experience and therefore had to be walked through this lab because I had no idea what I was actually calculating or what my giant numbers meant.

> I enjoyed the lab and hands on learning…math was kind of difficult to understand.

The assignment was subsequently modified for Spring 2008 to balance the mathematical computations with the larger concepts of groundwater in the Spring Creek alluvial aquifer relative to the High Plains regional aquifer. The revised exercise consists of three parts including a video of the well drilling and installation process and evaluation of drill core through logs and figures developed by Spence (2006; 2007), construction of a groundwater table map and comparing that map to regional groundwater flow, and evaluation of the water quality of groundwater versus surface water (Table II). The groundwater exercise is available on the Science Education Resource Center (SERC) website at http://serc.carleton.edu/NAGTWorkshops/intro/activities/groundwater.html.

RESULTS

Student Perception Survey

Demographics

Total use of the GetWET from Fall 2006–Spring 2008 included 715 students, of which 75% were enrolled in the GEOL121 course because it satisfies a general science laboratory requirement, with 25% enrolled as an elective. The vast majority of students are nongeology majors (82%), with 4% majors (n=29), and 10% in undecided or undeclared majors. Nearly 30% of students in GEOL121 are in the College of Liberal Arts, another 15% in Business, and 15% from Natural Resources, with remaining enrollment spread between the other academic colleges on campus. Student ethnicity is consistent with university demographics, with 81% of students classifying themselves as non-minority, and 14% minority, with 5% not reporting ethnicity. Given the large discrepancy between the number of nonminority and minority students enrolled in GEOL121, no inferential statistics were run on ethnicity data.

In an effort to ensure equal benefit to students from all disciplines, an analysis of students by college was conducted. There are no differences among students from different colleges in regard to quality of the laboratory,

TABLE III: Means, one-way analysis of variance (ANOVA) and p-values for academic colleges on four index variables (quality of the lab, lab satisfaction, quality of lesson, topic perceptions). Values are based on the scale 1=strongly disagree, 2=mildly disagree, 3=neither disagree nor agree, 4=mildly agree, and 5=strongly agree.

	UnD[1]	NR[1]	LA[1]	Bus[1]	NS[1]	AS[1]	AHS[1]	ANOVA *F*	p-value
Quality of lab	3.76	3.88	3.78	3.85	3.63	3.82	4.07	1.49	0.17
Lab satisfaction	3.28	3.50	3.13	3.19	3.19	3.47	3.42	1.90	0.07
Quality of lesson	3.54	3.65	3.59	3.65	3.60	3.60	3.71	0.34	0.94
Topic perceptions	3.60	3.75	3.48	3.61	3.44	3.61	3.75	1.32	0.24

[1]UnD=Undecided, NR=Natural Resources, LA=Liberal Arts, Bus=Business, NS=Natural Sciences, AS=Agricultural Sciences, and AHS=Applied Human Sciences.

satisfaction with the laboratory, quality of the lesson, or perceptions of surface and groundwater relationships and impacts (Table III). Students from all academic colleges within the university appear to have similar perceptions to each index variable, indicating the GEOL121 laboratory exercise using the GetWET Observatory is meeting the needs of students from all colleges equally.

Although enrollment of males and females is nearly equal, significant differences were found between males (n=181) and females (n=183) on three of the four composite variables. Males were found to be more satisfied with the laboratory experience, more satisfied with the quality of the lesson, and it seems they have a greater understanding of the relationship between themselves and surface and groundwater ($p<0.01$; $M_{males}=3.70$, SD=0.81; $M_{females}=3.48$, SD=0.80). Finally, males and females differ in how much the weather impacts their experiences at the GetWET, with females (M=3.62, SD=1.14) reporting that the weather had more of an impact on their experience than did males (M=3.27, SD=1.31, $p<0.01$).While the outdoor laboratory experience at the GetWET is scheduled to occur when the weather is most likely mild, the females are still reporting that weather impacts their experience. Presumably, this has some association with the fact the females' experiences at the GetWET are less positive overall compared to males.

Revised Groundwater Exercise

An independent samples *t*-test was conducted to judge the effects the revised laboratory assignment (between the Fall 2007and Spring 2008) had on students' perceptions of the quality of the laboratory, student satisfaction with the laboratory, perceptions of the quality of the lesson, and perceptions of surface and groundwater topics (Fig. 3). The *t*-test indicates a significant difference in the quality of the lesson with a medium, or typical, effect size. The students perceived the lesson to be higher quality ($p<0.01$) when the modified lesson was implemented (M=3.77, SD=0.80) over the previous semester when the assignment was more mathematically complex and less conceptually relevant (M=3.45, SD=0.75). There are no significant differences in the students' perceptions of the quality of the laboratory. Based on open-ended responses on the questionnaire after the implementation of the revised exercise, students still find the laboratory challenging mathematically, but more students are able to have a positive experience at the Observatory, while the content and intellectual rigor of the exercise is maintained.

Teaching Assistant Experience

There are significant differences in all four of the composite variables between those students with a graduate-level teaching assistant and those with an undergraduate-level teaching assistant (Fig. 4). Students whose teaching assistant was a graduate student had much higher perceptions of the quality of the lab [$t(288)=3.52$, $p<0.01$, $d=0.43$], higher satisfaction with the lab [$t(281)=2.65$, $p=0.01$, $d=0.33$], higher perception of the quality of the lesson [$t(282)=3.84$, $p<0.01$, $d=0.46$], and a higher understanding of the relationship between themselves and ground and surface water [$t(282)=3.95$, $p<0.01$, $d=0.49$]. Effect sizes are approaching medium, or typical, for each.

Pre- and Post-Knowledge Assessment

Student scores on knowledge tests (Table I) show an overall average positive gain after completing the laboratory exercises at the GetWET Observatory and Spring Creek. The pre-test mean ranged from 2.08 to 2.38 (out of a

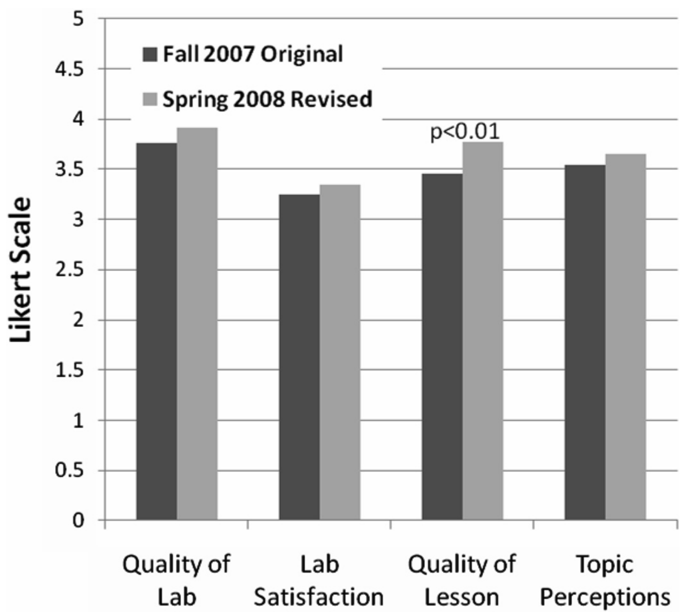

FIGURE 3: Differences between student perception surveys for GEOL121 Introductory Geology Laboratory during Fall 2007 (black) and Spring 2008 (gray) when the revised groundwater exercise was introduced. P-value shows significant difference. Values are based on the scale 1=strongly disagree, 2=mildly disagree, 3=neither disagree nor agree, 4=mildly agree, and 5=strongly agree.

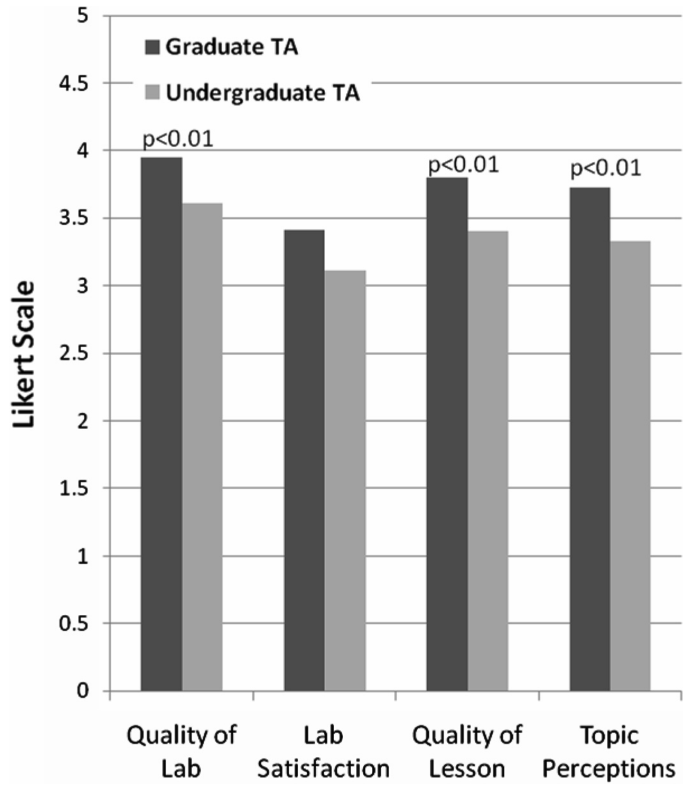

FIGURE 4: Differences in student perception surveys between individuals whose instructor is a graduate teaching assistant (black) versus an undergraduate teaching assistant (gray). Students with a graduate TA (n=194), and students with an undergraduate TA (n=97) over the study period (Fall 2007–Spring 2008). P-values show significant differences. Values are based on the scale 1=strongly disagree, 2=mildly disagree, 3=neither disagree nor agree, 4=mildly agree, and 5=strongly agree.

possible 5), and post-test mean from 2.75 to 3.10. All pretest means are not significantly different [$F(2,390) = 2.13$, $p = 0.12$] indicating a similar student knowledge baseline over the three semesters of data collection. An analysis of the gain scores show that the mean gains are significantly different [$F(2,390) = 19.84$, $p < 0.01$, $\eta^2 = 0.09$], with the post-revision gains in years 2008 and 2009 lower than were seen in 2007 before the revision. The effect size is medium, and indicates that the curricular revision accounts for approximately 9% of the overall variance in the test score gains. The greatest student gains were achieved during Fall 2007 when pre- and post-tests were administered in only those laboratory sections taught by graduate teaching assistants (smallest sample size). A gain score of 1.6 between student's pre- and post-test scores occurred when the original, more quantitatively challenging exercise was in use.

It is noteworthy that during this 2007 semester, two of the three graduate teaching assistants were Master's students in our hydrogeology program, and hence had a stronger background and interest in groundwater. Given that the knowledge baseline is similar for students during the study period, and the knowledge gains were less after revision of the groundwater exercise, we acknowledge the possibility that the revised exercise is actually less effective. Other sources of information lead us to conclude that additional factors were involved, however. Qualitative student feedback in class and end-of-semester evaluations from all sections in Fall 2007 indicate students were confused by the complex mathematical calculations of the original version. Also, teaching assistants in Fall 2007 uniformly reported students struggled to complete the original laboratory exercise and required more assistance outside of lab during office hours. In our view, the academic backgrounds of the teaching assistants and the small sample size render Fall 2007 an anomalous semester. During subsequent semesters when the revised exercise was introduced, pre- and post- tests were administered in all 17 sections of the GEOL121 Introductory Geology Laboratory taught by both graduate and undergraduate teaching assistants. Student and teaching assistant feedback during this time supported strong student understanding of fundamental concepts of surface and groundwater, albeit at a lower gain than what was measured between 2007 and exercise revision of 2008 and 2009, but without the noticeable student struggles to complete the exercise.

The analysis of the pre- and post-test scores revealed that during Spring 2008 not all sections of the laboratories showed average gains between pre- and post-knowledge tests. Student scores declined on average by -0.25 within all laboratory sections taught by one non-hydrogeology teaching assistant. After careful consideration of conditions during that period, it was concluded that misinformation had been conveyed to the students in two laboratory sections about groundwater characteristics and interactions with surface water. When scores for that teaching assistant's laboratory sections are removed, the average student gain during spring semester 2008 increased to 0.76 from 0.63 (Table I). To remedy the possibility of other teaching assistants communicating misinformation, additional training was implemented for teaching assistants (Fig. 1) to ensure thorough understanding of groundwater concepts prior to teaching the concepts in laboratory. Results from the most recent semester (Table I) indicate the additional teaching assistant preparation is helping to reduce the potential for misinformation being communicated.

Laboratory Satisfaction

Overall, student attitudes about the groundwater laboratory exercise and experience are positive. Students rate the GetWET experience high in terms of recommending it to others (86%) and feel they better understand surface water groundwater interactions. No disparity in student satisfaction was apparent for students with the one teaching assistant responsible for communicating erroneous information during the groundwater laboratory, in that students whose scores dropped between the pre- and post-test did not indicate diminished satisfaction with the laboratory experience. This is somewhat understandable, for students in sections taught by that teaching assistant were probably unable to discern the misconceptions introduced in lab, while still enjoying the overall lab experience.

DISCUSSION AND CONCLUSIONS

There is a clear need for sustained and comprehensive instruction regarding key surface water and groundwater concepts at the undergraduate, non-STEM major level to ensure a water literate public. The GetWET Observatory at

CSU provides a successful example of hands-on, field-based learning opportunities for students to gain functional knowledge about surface and groundwater concepts through a multipart exercise within their local watershed. Our data from student perception surveys indicate success in meeting the needs of all majors equally, that males generally enjoy the outdoor experience at the GetWET more than females, that weather has an impact on student satisfaction, and that revising an exercise can improve student understanding of concepts without losing intellectual and content rigor. In essence, the positive learning environment at the GetWET Observatory, which student perception data rate as high, sets the stage for improved student achievement. This is consistent with other research linking student perceptions of a laboratory to achievement indirectly through student attitudes (Newby and Fisher, 1998), where environmental factors in science laboratories have been shown to account for cognitive (McRobbie and Fraser, 1993) and affective (Lang *et al.*, 2005; McRobbie and Fraser, 1993; Martin-Dunlop and Fraser, 2007) outcomes. Learning environment and attitudes are similarly important for future primary school teachers (Martin-Dunlop and Fraser, 2007), many of whom enroll in our introductory geology courses and laboratories at CSU.

It is possible that differences in student and/or teaching assistant composition between Fall 2007 and Spring 2008 account for the improved perception of the quality of the lesson (Fig. 3), among other factors. For example, more freshmen enroll in GEOL121 during fall semester than during spring, and freshmen in general find the laboratory more difficult than older students. In addition, overall teaching assistant quality varies each semester, independent of how well assistants are prepared to teach. Those teaching assistants who invest time in the lab and enjoy teaching clearly influence student's perceptions of the quality of the lesson in a positive way. More than two semesters of student perceptions data would have been useful to understand whether or not the statistically significant increase in student satisfaction is an artifact of student or teaching assistant composition, or some other factor.

The highest gains on the post-tests occurred during a semester when only graduate teaching assistants administered the assessment, 2/3 of whom were in the Masters hydrogeology program in our department. The gains are thus influenced by an anomalous situation of teaching assistant experience, but also by the curricular revision, which accounts for approximately 9% of the overall variance in the test score gains. We felt that other qualitative data from students and teaching assistants were more informative and indicated the original exercise was too difficult for students. As a result, the assessment data from Spring 2008 and 2009 more likely reflect realistic gains in student knowledge based on teaching assistant backgrounds and total student enrollment in GEOL121. Additional pre- and post-tests are planned for future semesters to evaluate whether or not continued revision of the laboratory exercise is necessary to fully understand the initial decrease in content knowledge scores from Fall 2007 to Spring 2008 and 2009. Our goal is to maintain high student and instructional satisfaction with the quality of the lesson, and to measure unambiguous student knowledge gains between pre- and post-test scores.

Other findings from the GetWET indicate pre- and post-knowledge tests are useful for tracking basic groundwater knowledge of teaching assistants and their teaching effectiveness. Student gains on pre- and post- tests over two semesters ranged from 0.63 to 0.76, with up to a 1.6 increase when their graduate teaching assistants had more hydrogeological background. Additional and ongoing training of all GEOL121 teaching assistants has strengthened the overall learning experience for undergraduates at the GetWET. No matter how masterfully conceived and integrative an exercise, teaching assistants provide the final critical link in the learning continuum for students. We understand and fully appreciate the necessity for continued, adequate teaching assistant preparation for both undergraduate and graduate teaching assistants alike. We now offer a weekly teaching assistant seminar each semester where we model the learning to take place the following week in lab. This seminar appears to have remedied the problem of teaching assistant under preparation. We want to ensure that students enrolled in GEOL121 laboratory achieve the highest level of learning and accurate understanding of surface and groundwater processes and resource availability, especially given our one-time opportunity to educate non-STEM majors in general education lecture and laboratory courses.

Student attitude surveys provide necessary, easily obtained information for educators to assure an affirmative laboratory environment supports positive student attitudes so individual achievement can be maximized. It is our prediction that students, who gain maximum educational benefit from an experiential, field-based learning opportunity, like that at the GetWET Observatory, will carry their knowledge with them as citizen scientists faced with tough water-oriented ballot issues, deciphering media reports about local and regional water issues, and when making personal choices about water resources. The attributes of understanding local surface water and groundwater interactions in the context of water quantity and quality will more likely endure in students' postbaccalaureate lives than if they had completed a more traditional, in-class laboratory exercise.

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received an effective, relevant, and positive learning experience at the GetWET Observatory.

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REFERENCES

American Association for the Advancement of Sciences, 2004, Invention and impact: building excellence in undergraduate science, technology, education and mathematics (STEM) education, *in* Proceedings of April 2004 Conference: Washington, D.C., NSF-AAAS.

Bloom, B.S., Engelhart, M.D., Furst, E.J., Hill, W.H., and Krathwohl, D.R., 1956, Taxonomy of educational objectives: Handbook 1: Cognitive domain: New York, David McKay.

Bykerk-Kauffman, A., 1995, Using cooperative learning in college geology classes: Journal of Geoscience Education, v. 43, p. 309–316

Day-Lewis, F.D., Gray, M.B., Garfield, R.L., and Day-Lewis, A.D., 2006, An on-campus well field for hydrogeophysics education and undergraduate water research,: Journal of Geoscience Education, v. 54, p. 480–486.

Dickerson, D., and Dawkins, K., 2004, Eighth grade students' understandings of groundwater: Journal of Geoscience Education, v. 52, p. 178–181.

Dickerson, D., Callahan, T.J., VanSickle, M., and Hay, G., 2005, Students' conceptions of scale regarding groundwater: Journal of Geoscience Education, v. 53, p. 374–380.

Dunnivant, F., Brzenk,R., and Moore, A., 1999, A comprehensive stream study designed for an undergraduate non-majors course in Earth Science: Journal of Geoscience Education, v. 47, p. 158–165.

Elkins, J.T., and Elkins, N.M.L., 2007, Teaching geology in the field: Significant geosciences concept gains in entirely field-based introductory geology courses: Journal of Geoscience Education, v. 55, p. 126–132.

Fletcher, F., 1994. A hydrogeologic field laboratory for undergraduate instruction and research: Journal of Geological Education, v. 42, p. 491–493.

Fraser, B.J., 1994. Research on classroom and school climate, *in* Gabel, D., ed., Handbook of research on science teaching and learning: New York, Macmillan, p. 493–541.

Hudak, P., 1999, Groundwater field station for geosciences students: Journal of Geography, v. 98, p. 23–28.

Kirchner, J.G., 1994, Results of an alumni survey on professional and personal growth at field camp: Journal of Geoscience Education, v. 42, p. 125–128.

Kolb, D.A., 1984, Experiential learning: Experience as a source of learning and development: Englewood Cliffs, NJ, Prentice-Hall, p. 241.

Lang, Q., Wong, A., and Fraser, B., 2005, Student perceptions of chemistry laboratory learning environments, student-teacher interactions and attitudes in secondary school gifted education classes in Singapore: Research in Science Education, v. 35, p. 299–321.

Laton, W. R., 2006, Building groundwater monitoring wells on campus: A case study and primer: Journal of Geoscience Education, v. 54, p. 50–53.

Martin-Dunlop, C., and Fraser, B., 2007, Learning environment and attitudes associated with an innovative science course designed for prospective elementary teachers: International Journal of Science and Mathematics Education, v. 6, p. 163–190.

McRobbie, C., and Fraser, B., 1993, Association between student outcomes and psychosocial science environment: Journal of Educational Research, v. 87, p. 78–85.

Meyer, W.B., 1987, Vernacular American theories of earth science: Journal of Geological Education, v. 35, p. 193–196.

National Research Council, 1997, From analysis to action: Undergraduate education in science, mathematics, engineering, and technology: Washington, D.C., National Academy Press.

National Science Foundation, 1996, Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology: Report 96-139, p. 76.

Newby, M., and Fisher, D., 1998, The association between computer laboratory environment and student outcomes, Paper presented at the Australian Association for Research in Education Annual Conference, Adelaide, Australia, retrieved from http://www.eric.ed.gov/ERICWebPortal/contentdelivery/servlet/ERICServlet?accno=ED434910.

Plymate, T.G., Evans, K.R., Gutirrez, M., and Mantei, E.J., 2005, Alumni of Geology B.S. program express strong support for field geology and related field and laboratory experiences: Journal of Geoscience Education, v. 53, p. 215–216.

Rahn, P.H., and Davis, A.D., 1996, An educational and research well field: Journal of Geoscience Education, v. 44, p. 506–517.

Rathburn, S., Warnock, A., Sanford, W., and Harry, D., 2006, The Colorado State University GetWET Observatory: A fluid learning environment promoting deeper understanding: Geological Society of America Abstracts with Programs, v. 38, p. 429.

Richardson, J. R., 1998, Overview of the July 1997 Spring Creek flood, Fort Collins, Colorado, *in* Abt, S.R., ed., Proceedings of the International Water Resources Engineering Conference, Reston, VA: Fort Collins, CO, Colorado State University, p. 33–38.

Rimal, N.N, and Stieglizt, R.D., 1997, Using available resources to enhance teaching of hydrogeology: Journal of Geoscience Education, v. 48, p. 508–513.

Saunders, W.L., 1992, The constructivist perspective: implications and teaching strategies for science: School Science and Mathematics, v. 92, p. 136–141.

Siebert, E.D., and McIntosh, N.J., 2001, College pathways to the National Science Education Standards, Arlington, VA: NSTA Press, p. 192.

Spence, C.J., 2006., Site characterization of the GetWET Observatory at CSU, Research Experience for Undergraduates—Program in water research at Colorado State University, informal final report submitted during final symposium.

Spence, C.J., 2007. Surface-groundwater interactions in a test well field and Spring Creek, Fort Collins, CO, senior [Thesis]: Department of Geology, Carleton College, Northfield, MN, p. 40.

Springer, L., Stanne, M.E., and Donovan, S., 1998, Effects of cooperative learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis, Research Monograph No. 11: Madison, University of Wisconsin-Madison.

Wampler, J.M. 2000, Misconceptions—A column about errors in geosciences textbooks: Confusion about the role of infiltration in the hydrologic cycle, Journal of Geoscience Education: v. 48, p. 382–385.

Warnock, A.C., Rathburn, S.L., and Thompson, S., 2004, Geology of Lory State Park: Colorado, Rocky Mountain Nature Association, p. 16.